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This article discusses the fact that if practice continues long enough, most subjects will stop improving before the practice ends. In such a case, individual subjects may be said to differ in how much they are "overpracticed" at their end-of-practice levels. If practice is relatively short, however, almost all subjects will still be improving when it ends. In this case, subjects differ in rate of improvement late in practice, even though no subject may be overpracticed. In this article, evidence is presented that when end-of-practice level is statistically controlled, the more an individual is overpracticed at his or her end-of-practice level, or the more slowly he or she is improving late in practice, the better skill retention tends to be. Evidence is also presented that rate of improvement early in practice has no effect on retention not mediated by end-of-practice level, and either overpractice or rate of improvement late in practice.

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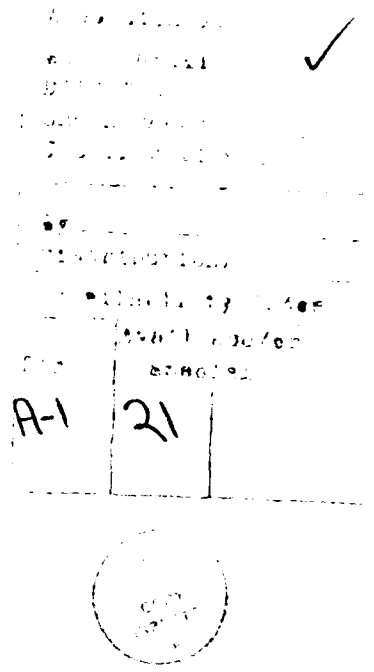

INDIVIDUAL DIFFERENCES IN SKILL RETENTION

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ABSTRACT

If practice continues long enough, most subjects will stop improving before practice ends. In such a case, individual subjects may be said to differ in how much each one is "overpracticed" at his or her end-of-practice level. If practice is relatively short, however, almost all subjects will still be improving when practice ends. In this case subjects differ in rate of improvement late in practice, even though no subject may be overpracticed. In the present study evidence is presented that when end-of-practice level is statistically controlled, the more an individual is overpracticed at his or her end-of-practice level or the more slowly he or she is improving late in practice, the better skill retention tends to be. Evidence is also presented that rate of improvement early in practice has no effect on retention not mediated by end-of-practice level and either overpractice or rate of improvement late in practice.

The effects of overpractice on retention are both long and well-established: overpractice improves retention (Goldberg, Drillings, & Dressel, 1981; Hamınerton, 1963; Krueger, 1929; Luh, 1922; Melnick, 1971). In all of these experiments, "overpractice" is defined as the amount of additional practice that a subject is given after correct performance has been achieved. Luh, for example, had his subjects memorize lists of 12 nonsense syllables. In the overpractice condition (150%), "the subject was given one half of the number of presentations in addition to what was required for the first errorless anticipation of a series. Thus, if a series was learned in 10 presentations, 5 more were given" (Luh, 1922, p. 43). Since overpractice begins with 100% correct performance, a subject's level of performance does not change during overpractice; the acquisition curve is flat. Nevertheless, retention is improved over what it would have been without overpractice.

So defined, overpractice is an experimental treatment. Whether it applies or does not apply depends on the experimental design. Suppose, however, that one wishes to predict individual levels of performance at reacquisition, where all subjects are given the same number of trials in acquisition. Some subjects may arrive quickly at their final levels of performance, while others may not do so until just before practice ends. The former, it can be argued, are overpracticed because practice continues for them when they are no longer improving, whereas the latter subjects are not overpracticed because they receive little or no additional practice after reaching their final levels. Overpractice in this second sense is not an experimental treatment but an individual difference; it refers to the shape of individual acquisition curves.

The first hypothesis to be tested in this paper is that overpractice as an individual variation affects retention the same way it does as an experimental treatment. This possibility has never been investigated, and the experimental evidence by no means guarantees that any such extrapolation to the individual level holds true. Individual performance after a lengthy period of time without practice is known to depend on performance at the end of acquisition (Fleishman & Parker, 1962; Naylor & Briggs, 1961; Schendel et al., 1978; Hagman & Rose, 1983). If the shape of an individual's performance curve, as well as its level, contributes to retention, a new component will be added to both our prediction equations and our understanding of individual performance at retention.

Rate of increase late in acquisition

Overpractice as an individual difference does not necessarily occur; it depends on how long practice continues. If practice is relatively short, then all or almost all subjects will still be improving when practice ends. They may not, however, be improving at the same rate. Some may be improving slowly and others rapidly. It would be a mistake to include these differences in slope under the term "overpractice" because one can point to no specific response or level of response that is overpracticed. Nevertheless, shallow slope bears an obvious affinity to overpractice in that a flat curve (overpractice) is the limiting case of increasingly shallow slope. No response may be overpracticed, but the slower the rate of increase late in practice the more opportunity there is for consolidation to occur.

The second hypothesis to be tested is that where practice does not continue long enough for overpractice to occur, rate of increase late in practice (RILP) relates to retention. Slow rates make for better retention.

Rate of increase early in acquisition

Underwood (1949, p. 510) stated as a general principle that "when learning is rapid, forgetting will be slow, and when learning is slow, forgetting will be rapid." When he laid down this principle, Underwood was referring to experimental conditions rather than individual differences. All of the evidence he cited, for example, massed versus distributed practice, meaningfulness of material, and intra-task similarity, concerned variations in the task or in the way it was administered. In recent years, however, individual differences in rate of early acquisition have attracted attention as a possible predictor of performance at the end of practice, mainly on cognitive tasks (Ackerman & Schneider, 1984; Allen et al., 1983, 1984, 1985; Kyllonen, 1986; Kyllonen et al., 1984). The present report focuses on overpractice and RILP. Attention is also paid, however, to rate of increase early in practice (RIEP).

STUDY 1

The first study was carried out in a small sample (N = 27) of Navy enlisted volunteers. Each subject practiced the same six microcomputer-video tasks and in the same order. Video games were used because the alternatives for psychomotor testing are much less attractive in terms of ruggedness, the space they occupy, weight, cost, ease of replacement, maintenance, and availability (Kennedy et al., 1982). The six tasks selected for study were chosen on the basis of stabilization with practice and task definition (Jones, 1972). Other video-computer tasks also studied in the volunteer population either did not stabilize with practice or did so with poor task definition (Jones, 1981). Reacquisition was begun on the six tasks after intervals of no practice ranging in three well-separated levels from 4 to 18 months.

METHOD

Subjects

The 27 volunteers were all males between 19 and 24 years of age and with 20/20 corrected vision. The sailors were paid for their participation in accordance with Navy guidelines.

Procedure

Each task was practiced one session a day for 15 consecutive working days. The six tasks were practiced in the following order: Air Combat Maneuvering (ACM), Breakout, Race Car, Pong, Basketball, and Anti-Aircraft, the last two concurrently. Table 1 presents details on each task, including trial length, number of trials per day, and dependent measure (score). Race Car, for example, is game #2 in the Atari Indy 500 cartridge (CX-2511). In playing any of these games the player has the option of setting a difficulty switch on the game console. "A" is hard and "B" easy. In the case of Race Car difficulty level controls the maximum speed at which the car travels. When the switch is set at "A", the car travels at higher speeds making it more difficult to control. The purpose of the game is to complete as many laps as possible in the 60 seconds allowed; whenever the car crashes into a boundary or barrier, time is lost. The control devices are a special knob which functions as a steering wheel and a button which functions as an accelerator. Each trial lasted 60 seconds and each sailor received 15 trials a day. Intertrial interval was not strictly controlled but never lasted more than one minute and usually much less. The dependent measure was number of laps completed.

Practice was resumed on Race Car and Pong after an interval of 4-6 months, on Basketball and Anti-Aircraft after 10-12 months, and on ACM and Breakout after 16-18 months. All retention intervals were measured from the

15th day of acquisition on that particular task to the first day of reacquisition. Each task was repracticed for five consecutive working days, with the same number of trials per day as was used in acquisition. The two tasks in the same retention interval, for example, Race Car and Pong, were repracticed concurrently. That is, both tasks were practiced on the same five consecutive working days. All subjects were instructed not to practice any of the six tasks during the no-practice interval.

The number of subjects who completed the experiment varied from retention interval to retention interval. Seventeen sailors completed work on Race Car and Pong, 16 on Basketball and Anti-Aircraft, and 13 on ACM and Breakout. The subjects who completed the longer intervals were not all nested among those who completed the shorter ones. Three sailors, for example, were already more than a year past acquisition on Basketball and Anti-Aircraft when the decision to carry out a retention study was made. These three sailors could be repracticed only on ACM and Breakout. Other sailors were transferred after repracticing two or four but not all six tasks.

Insert Table 1 about here

In all tasks the dependent measure appeared on the viewing screen throughout play; it was the quantity the subject was trying to maximize. A player's score was the value of the dependent measure when the game ended. A subject's score on any given day (session) was the mean score of the games he played that day. Thus for each subject and task, analysis begins with 20 data points--15 in acquisition and 5 in reacquisition.

Results are analyzed for the first reacquisition session only. The remaining four reacquisition sessions are the focus of another report.

Results

Average performance. Figure 1 presents means and standard deviations in both acquisition and reacquisition for the six tasks. The average-performance curves for Race Car, Pong and Basketball decelerate more strongly than those for Anti-Aircraft, ACM, and Breakout. The standard-deviation curves are essentially flat after the first few sessions, except possibly for ACM and Breakout where there appears to be a tendency for variability to increase slightly with the mean.

Insert Figure 1 about here

Individual performance. In Study 1 practice continued long enough that a subject's performance on day 15, the last in acquisition, was not always or even usually his best; on all tasks most subjects performed at least as well on an earlier day as they did on day 15 and, therefore, had at least one day of overpractice. In this case, therefore, overpractice occurred. The measure used was "15 minus the number of the session on which the subject first reached or exceeded his score on session 15." A subject who performed better on day 15 than on any earlier day received a score of 0. A subject who first reached or exceeded his end-of-practice level on day 10 received a score of 5. On all tasks amount of overpractice varied widely. On Race Car, for example, overpractice ranged from 0 to 13 with a mean of 3.7 and a standard deviation

of 4.5. ACM was least overpracticed but even it had scores ranging from 0 to 9 with a mean of 1.7 and a standard deviation of 2.5.

RIEP was measured over the interval from session 1 to the point where overpractice began. If a subject first reached or exceeded his end-of-practice (EOP) level on session 10, a straight line was fit to that subject's mean performance in sessions 1 through 10. RIEP was indexed by the slope of this regression line. Since different subjects reached their EOP levels after different amounts of practice, the length of the interval over which RIEP was calculated varied from subject to subject. Its meaning, however, remained the same, namely, the amount a subject improved per session (on the regression line) prior to reaching his EOP level and going into overpractice.

A subject's EOP level was his score on day 15 (X_{15}). Absolute retention was a subject's performance level on the first day of reacquisition (X_{16}). Relative retention was the difference between absolute retention and EOP level (X_{16}-X_{15}). Table 2 contains the zero-order correlations (that is, not controlling for any other variables) between RIEP, overpractice, and EOP level as predictors and absolute and relative retention as criteria.

Insert Table 2 about here

RIEP is weakly and inconsistently related to absolute retention. The largest correlation, the one for ACM (.55), is positive and significant just short of the .05 level. The correlations between RIEP and relative retention are stronger and more positive, two being significant at or beyond the .05 level.

Only one of the six correlations with relative retention is negative and it very weakly so.

Overpractice correlates weakly and inconsistently with absolute retention but positively and strongly with relative retention. The correlations range from .38 to .83, all positive, and four out of six are significant at the .01 level.

The correlations for EOP level are consistently positive with absolute retention, significantly so in three of the six tasks, and consistently negative with relative retention. The latter result is, of course, to be expected since EOP level appears with reversed sign in $(X_{16}-X_{15})$.

Table 3 contains the same correlations as Table 2 except that in each case the other two predictors are controlled statistically. Also, only one correlation appears for RIEP and overpractice with the two retention measures. The zero-order correlations with absolute and relative retention may, of course, be different; but the partial correlations controlling for EOP level are always the same because the partial correlation between absolute and relative retention controlling for EOP level is unity.

Insert Table 3 about here

When overpractice and EOP level are controlled, RIEP no longer has any but nonsignificant and inconsistent correlations with retention. Only one correlation is at all sizable and that one is negative (-.46).

Overpractice, on the other hand, continues to correlate positively with retention when the other two predictors are controlled. Two of the six

correlations are significant at the .05 level or better and a third (the one for ACM, .60) falls just short of significance at the .05 level ($p = .051$).

The correlations of EOP level with absolute retention are even stronger when the other two predictors are controlled than when they are not. The correlations of EOP level with relative retention, in contrast, become weak, nonsignificant, and inconsistent as to sign.

Altogether, EOP level relates strongly to absolute retention and overpractice to relative retention in both analyses. RIEP has no consistent relations with either absolute or relative retention not mediated by overpractice or EOP level.

STUDY 2

Study 1 involved a single sample of subjects with different tasks repracticed after different retention intervals. The one sample was small, each task was extensively practiced in acquisition, and retention intervals were long, ranging up to 18 months. Study 2 differed in all these respects. The new design called for three samples of approximately 50 subjects each, with each sample to be practiced on one task only, the task varying from sample to sample, and repracticed after a single relatively short interval of time, four months. Also, the amount of practice in acquisition was reduced.

Subjects

The subjects were all college students at three Central Pennsylvania colleges: Elizabethtown College, Lebanon Valley College, and the Capitol Campus of Pennsylvania State University. All subjects were between 18 and 28 years old with 20/20 corrected vision. The numbers of subjects at the three campuses were:

Elizabethtown, 33 females and 17 males

Lebanon Valley, 27 females and 29 males

Capitol Campus, 19 females and 34 males.

Each student was paid $50 for his or her participation in the study.

Procedure

Each subject was given five practice sessions on one of the three video-computer tasks: ACM at Elizabethtown, Race Car at Lebanon Valley, and Anti-Aircraft at Capitol Campus. In the cases of ACM and Anti-Aircraft, each session consisted of seven, 2-minute-and-16-second games, a total of 15 minutes and 52 seconds of playing time. Each session of Race Car consisted of 16, 1-minute games. In all three cases, the five practice sessions were completed within a 10-day period, with no more than two sessions taking place on a given day.

Reacquisition was begun approximately four months after acquisition was completed. Each subject was given three practice sessions with the same number of games per session and the same conditions as to distribution as in acquisition. Again, results are analyzed for the first reacquisition session only.

Few subjects in any of the three samples in Study 2 performed as well in any earlier session as they did in session 5. In this case, therefore, overpractice did not occur and hypothesis 2 became appropriate. RILP was indexed by the slope of the regression line over the last half of practice (sessions 3 through 5) and RIEP was indexed by the slope of the regression line over the first half of practice (sessions 1 through 3).

Average performance. The mean-performance curves for the three tasks followed much the same courses in acquisition as are depicted for the same

tasks in Figure 1, provided that the latter three curves are truncated after day 5. The standard-deviation curves are also much the same in acquisition, with the same proviso. In retention, however, there were some differences. Specifically, Anti-Aircraft and ACM did not drop as much over the no-practice interval in Study 2 as they did in Study 1, probably because the no-practice intervals were shorter for these two tasks in Study 2 then in Study 1.

Table 4 presents the average increase from session 3 to session 5 and the average decrease from session 5 to session 6, by task and sex. For all three tasks, males perform better throughout both acquisition and retention. This latter result is not peculiar to these tasks but is characteristic of almost all video-computer games (Jones, 1984).

The main result in Table 4 is that for all three tasks whichever sex gains more in the last half of acquisition loses more over the no-practice interval. In Race Car it is the women, while in the other two tasks it is the men. For Race Car and Anti-Aircraft the differences for both RILP and loss over the following no-practice interval are statistically significant (see Table 4 for levels). For ACM neither difference comes close to significance.

Insert Table 4 about here

These results confirm hypothesis 2 at a group level. Whichever sex improves more slowly late in practice (males in Race Car, females in Anti-Aircraft and ACM) preserves its mean level of performance better over the no-practice interval.

Individual performance. Table 5 contains the partial correlations between predictors and criteria, exactly as in Table 3 except that sex is also controlled. The results are essentially the same on all counts as in Study 1. EOP level relates positively and very strongly to absolute retention, all three correlations being significant well beyond the .001 level.

"Shallow RILP" (that is, RILP with reversed sign) relates positively and consistently to (absolute/relative) retention, two of the three correlations being significant at the .05 level or beyond. The zero-order correlations with relative retention, not shown in Table 5, are also all positive (.59, .48, and .33 for Race Car, Anti-Aircraft, and ACM respectively) and all significant at the .05 level or beyond.

The zero-order correlations for Race Car and ACM between RIEP and absolute retention, also not shown in Table 5, are both significant at the .05 level but with opposite sign (-.42 for Race Car and +.31 for ACM). Both correlations, however, become weak and nonsignificant when RILP and EOP level are controlled. Again, therefore, RIEP has no relation to retention not mediated by the other two predictors, RILP (in this case) and EOP level.

GENERAL DISCUSSION

Overpractice and RILP

The main result of these two studies is the consistently positive relation between overpractice or shallow RILP and relative skill retention. This relation holds true for both zero-order correlations and when the other two predictors are controlled. The latter finding means that overpractice and shallow RILP contribute to relative retention in ways not mediated by either RIEP or EOP level.

RIEP

Significant zero-order correlations between RIEP and either absolute or relative retention were obtained in 5 out of 9 possible cases. In 4 of those 5 cases the direction agreed with Woodrow's principle that rapid learning makes for good retention. None of these relations, however, continued to hold after the other two predictors were statistically controlled. RIEP related to absolute or relative retention in no way not mediated by overpractice or RILP and EOP level.

These results can be explained straightforwardly. If a subject learns rapidly, then he or she will tend either to have a high EOP level or to arrive quickly at a lower one and, therefore, either to overpractice or to have shallow RILP. In the first case (high EOP level) the result will be good absolute retention and in the second (overpractice or shallow RILP) good relative retention. In some tasks it will be one and in some the other; both were obtained in these studies. On this interpretation, RIEP may relate to retention but, when it does, the relationship is not direct but externally mediated by overpractice or RILP and EOP level.

Notes

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Table 1. Information regarding the six video-computer tasks in Study 1

NAME		CASSETTE, GAME	DIFFI-CULTY	TASK DESCRIPTION	CONTROL DEVICE	TRIAL LENGTH	TRIALS/ DAY	SCORE
I)	Race Car	Indy 500 (CX-2511), Game 2	Left=A* Right=A	Car must drive around course & attempt to avoid hitting wall (hitting wall slows car down)	special knob, button	60 sec	15 trials/day	# of laps completed around the course
II)	Pong	Video Olympics (CX-2621), Game 2	Left=B Right=A	Ball is rallied back and forth from computer to S	paddle, button	1st to score 21	3 trials/day	player's percentage of total points
III)	Basketball	Basketball (CX-2624), Game 2	Left=A Right=A	Player must score baskets while preventing a computer controlled cursor from scoring	joystick, button	4 min	4 trials/day	# of baskets x 2
IV)	Anti-Aircraft	Air Sea Battle (CX-2602), Game 1	Left=A Right=A	Shoot down over-passing jets from a stationary platform	joystick, button	2 min 16 sec	7 trials/day	# of planes shot down
V)	Air Combat Maneuvering	Combat (CX-2601), Game 24	Left=B Right=B	Attack and shoot down opposing jet from one's own jet	joystick, button	2 min 16 sec	10 trials/day	# of times opposing jet is hit
VI)	Breakout	Breakout (CX-2622), Game 1	Left=B Right=B	Ball ricochets from brickwall and is reutrned by paddle	paddle, butcon	5 balls	10 trials/day	# of bricks knocked down (each "wall" of bricks is worth dif-erent # of points)

*The "Left" difficulty control applies to the player and the "Right" control to the computer or second player.

Table 2. Zero-order correlations in Study 1 between RIEP, overpractice, and EOP level as predictors and absolute and relative retention as criteria

	RIEP		Overpractice		EOP Level	
Task	Abs	Rel	Abs	Rel	Abs	Rel
Race Car	-.14	.63**	-.12	.78***	.44	-.72***
Pong	.25	.53*	.31	.70**	.32	-.44
Basketball	-.20	.03	.02	.48	.23	-.48
Anti-Aircraft	-.12	-.09	.03	.83***	.65**	-.49
ACM	.55	.46	.15	.80***	.69**	-.48
Breakout	.02	.39	.03	.38	.67**	-.51

*p < .05. **p < .01. ***p < .001.

Table 3. Partial correlations in Study 1 between RIEP, overpractice, and EOP level as predictors and absolute and relative retention as criteria, controlling in each case for the other two predictors

Task	RIEP Abs/Rel	Overpractice Abs/Rel	EOP Level Abs	EOP Level Rel
Race Car	-.00	.41	.60*	-.22
Pong	-.01	.57*	.54*	-.22
Basketball	-.28	.41	.47	-.06
Anti-Aircraft	-.46	.82***	.90***	.16
ACM	-.34	.60	.79**	.19
Breakout	.15	.02	.71*	-.44

*p < .05. **p < .01. ***p < .001.

Table 4. Average increase from Session 3 to Session 5 and average decrease from Session 5 to Session 6 in Study 2, by sex

Task	Measure	$(\bar{X}_5 - \bar{X}_3)^*$	$(\bar{X}_5 - \bar{X}_6)$
Race Car	Male (Δ_M)	0.66	0.02
	Female (Δ_F)	1.40	0.36
	($\Delta_M - \Delta_F$)	-0.74	-0.34
	t	5.87	3.19
	p	$<.001$	$<.001$
Anti-Aircraft	Male (Δ_M)	4.23	1.65
	Female (Δ_F)	2.07	0.04
	($\Delta_M - \Delta_F$)	2.16	1.61
	t	2.42	2.30
	p	$<.02$	$<.03$
ACM	Male (Δ_M)	2.33	0.13
	Female (Δ_F)	1.80	−0.13
	($\Delta_M - \Delta_F$)	0.53	0.26
	t	1.13	0.53
	p	$>.15$	$>.40$

* Average increase from Session 3 to Session 5 is numerically identical to twice the mean RILP.

Table 5. Partial correlations in Study 2 between RIEP, shallow RILP, and EOP level as predictors and absolute and relative retention as criteria, controlling in each case for the other two predictors and sex

Task	RIEP Abs/Rel	shallow RILP Abs/Rel	EOP Level Abs	EOP Level Rel
Race Car	-.05	.53***	.94***	-.30
Anti-Aircraft	-.08	.24	.73***	-.42**
ACM	-.22	.33*	.80***	.08

*p < .05. **p < .01. ***p < .001.

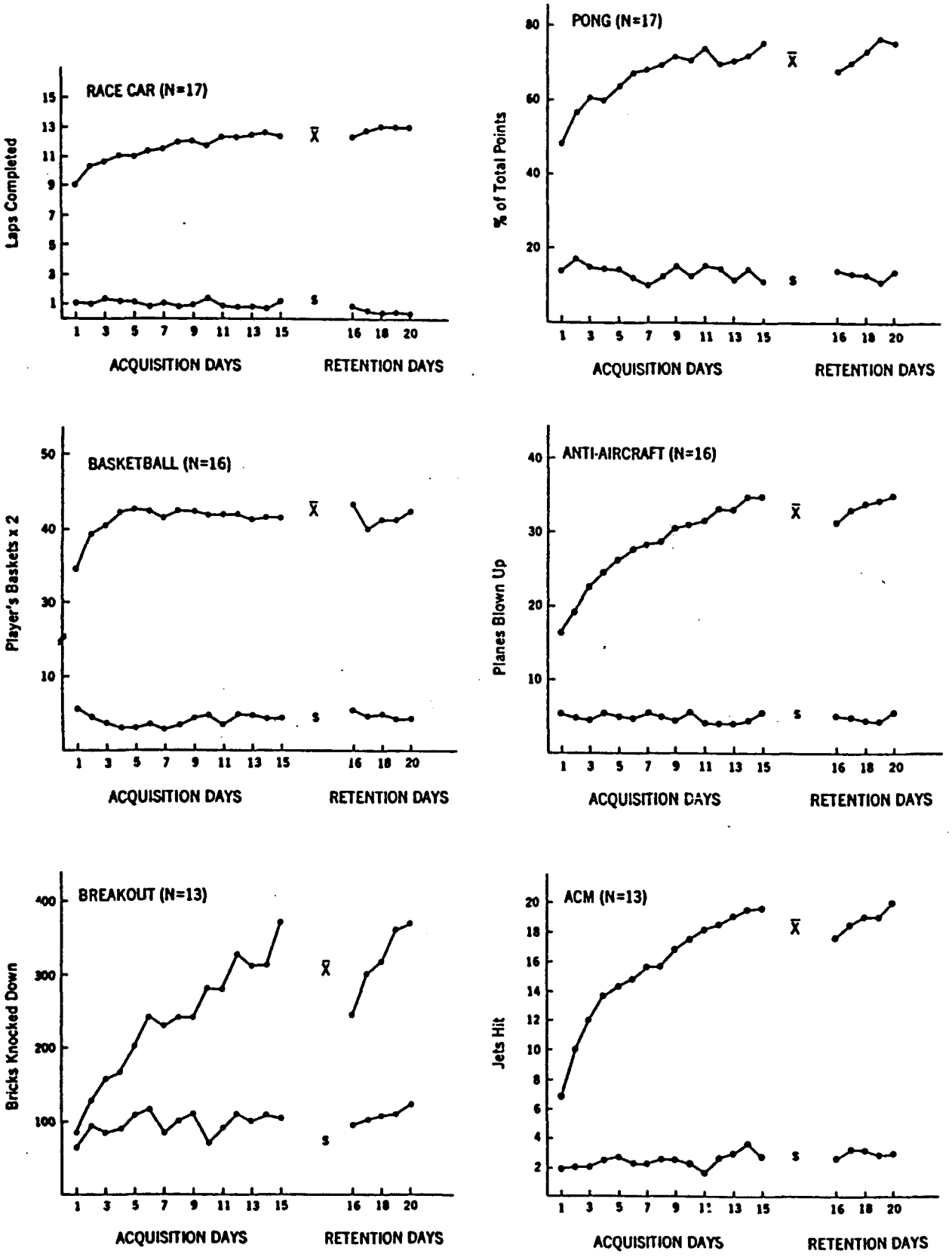

Figure 1. Means and standard deviations in acquisition and retention for Race Car, Pong, Basketball, Anti-Aircraft, ACM, and Breakout in Study 1